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Analysis of Influence of the Spray Angle on Sprinkling Intensity Distribution in the Spray Stream Produced by the Selected Turbo Type Fire-Hose Nozzle

Abstract

In the following article there has been assessed the influence of the spray angle on sprinkling intensity distribution in the spray water stream generated by the selected fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER produced by AWG company. The research was performed in the open air in August and September 2017. The field of measurements was located in front of the gate of The Firefighting and rescue equipment laboratory. A slightly modified test stand, which is normally used for researching fire-hose nozzles, was used to carry out the experiments. The measurements of the sprinkling intensity were performed on the basis of the authorial improved test methodology patterned upon the guidelines included in the old Polish PN-89/M-51028 standard. The parameter of sprinkling intensity has been assessed in weight and volumetric way using the measuring containers. The digital angle measuring device was used to measure the spray angle. The following article presents only the results of research, which was carried out for two water flow rates 200 dm^3/min and 400 dm^3/min and three spray angles: 30°, 60° and 90°, but all experiments were performed for two different water flow rates (200 dm^3/min and 400 dm^3/min) and six spray angles (15°, 30°, 45°, 60°, 75° and 90°). Based on the results of the conducted research it has been clearly demonstrated that the spray angle is a very important parameter which has an influence on sprinkling intensity distribution in the spray water streams produced by the selected fire-hose nozzles. It was observed that along with the changes of the spray angle the values of many parameters, which describe sprinkling intensity distribution, have been changed. The following parameters have been adopted for this research: the value of the sprinkling area and its dimensions (shape), the maximum throw (range) of the produced spray streams and the maximum value of the sprinkling intensity. In the last part of this article a summary and some conclusions have been made, of both, academic significance and practical character. In addition, the necessity and validity of the subsequent research has been indicated, in particular, using modern fire-hose nozzles.

Keywords: sprinkling intensity distribution, spray angle, fire-hose nozzle, spray streams, extinguishing efficiency

Analiza wpływu kąta rozpylenia na rozkład intensywności zraszania w strumieniu rozpylonym wytwarzanym przez wybraną prądownicę wodną typu Turbo

Abstrakt

W artykule dokonano oceny wpływu kąta rozpylenia na rozkład intensywności zraszania w strumieniu rozpylonym, wytwarzanym przez wybraną prądownicę wodną PWT 52/1-2-3-4 typ TURBOMASTER, produkowaną przez firmę AWG. Badania wykonano na otwartej przestrzeni w okresie sierpnia i września 2017 r. Stanowisko badawcze zlokalizowano na placu przed bramą Pracowni Sprzętu Ratowniczo-Gaśniczego. Do przeprowadzenia doświadczeń wykorzystano częściowo zmodyfikowane stanowisko laboratoryjne, służące nominalnie do badania prądownic wodnych. Pomiarów intensywności zraszania dokonano wykorzystując autorsko udoskonaloną metodę badawczą pochodzącą ze starej polskiej normy PN-89/M-51028. Parametr ten określano w sposób wagowo-objętościowy z użyciem pojemników pomiarowych. Do pomiaru kąta rozpylenia wykorzystano kątomierz elektroniczny. W niniejszym artykule przedstawiono jedynie wyniki badań wykonanych dla wydajności 200 dm^3/min i 400 dm^3/min oraz trzech kątów rozpylenia: 30°, 60° i 90°, choć całość pomiarów została przeprowadzona dla sześciu różnych kątów rozpylenia (15°, 30°, 45°, 60°, 75° i 90°). Otrzymane rezultaty wskazują jednoznacznie, że kąt rozpylenia jest bardzo ważnym parametrem mającym wpływ na rozkład intensywności zraszania w strumieniach rozpylonych wytwarzanych przez prądownice wodne typu Turbo. Zaobserwowano bowiem, że wraz ze zmianą kąta rozpylenia, zmianie ulegają wartości wielu parametrów, opisujących rozkład intensywności zraszania. Do przeprowadzenia analizy przyjęto następujące wskaźniki: powierzchnię zraszania i jej wymiary (kształt), maksymalną długość rzutu prądu rozproszonego oraz maksymalną intensywności zraszania. Na koniec sformułowano wnioski istotne zarówno w aspekcie teoretycznym, jak i praktycznym. Ponadto wskazano konieczność i zasadność prowadzenia dalszych prac badawczych, zwłaszcza z użyciem nowoczesnych prądownic wodnych.

Słowa kluczowe: rozkład intensywności zraszania, kąt rozpylenia, prądownica wodna, strumienie rozpylone, skuteczność gaśnicza

Introduction

The basic task carried out by the firefighters all over the world is to fight fires. The most common and the most effective extinguishing agent is still 'ordinary' water. Despite many advantages, water has some drawbacks and limitations. In certain situations extinguishing by water is even strongly prohibited. Therefore, it is a very important issue to apply water jets into fire and flames in a proper way. Water streams used during the firefighting and rescue actions should be correctly formed and applied to maximize extinguishing efficiency [1]. In the 1950s it was observed that the spray water streams have better extinguishing properties than the straight water jets [2]. It has been proved that the level of usage of water in spray streams is very high and its influence on the flames seems to be getting more effective. Thus extinguishing efficiency is significantly better [3]. Nowadays the researchers from all over the world are trying to solve the problem of optimization of extinguishing process, using water. This clearly means that firefighting and rescue actions must be carried out to extinguish the fire as fast as possible using minimal required water together with causing as small as possible water damages [1, 4–5].

The process of liquids atomization is defined as disintegration of water stream into droplets caused by the impact of various forces, especially surface, gravitational and aerodynamics [6]. One of the necessary conditions to initiate this process is to supply the kinetic energy in a proper way [7]. In many situations, it is the energy of the flowing liquid [8]. Nowadays, the Turbo type fire-hose nozzles are the most frequently used devices to apply the spray water stream to fight the fires during the firefighting and rescue actions. Wide range of usage possibilities is the biggest advantage. Thanks to the Turbo type fire-hose nozzles the water jets with different shapes and parameters can be obtained. According to the construction and structure of this type of the nozzles, they should be classified as the stream-whirl atomizers. Currently, the fog nozzles are available, which are used, for example, to form and apply mist streams. For instance, this type of devices are produced by the Mis-Tech LLC company from Kielce.

In spite of significant diversification of water streams, the parameters, which are used to describe and compare the jets, are set apart and classified. They are divided into external and internal parameters. The first one is connected with the macrostructure of the spray, but the second one with their microstructure. There are the following external parameters: the mass or the volume flow, the spray angle, the throw length and the liquid distribution in the stream of droplets. The mean diameters of droplets and the atomization spectrum are two internal parameters [6]. In fire safety engineering the liquid distribution in the stream of droplets is characterized by the factor called sprinkling intensity I_z. This parameter is defined as the volume of water fallen on the surface unit in a certain period. It is determined in an experimental way. The sprinkling intensity is one of the key factors used to assess the extinguishing efficiency of the water jet. It is proved, based on the experiments conducted during many ages, that there is a strong correlation between the level of atomization of the spray stream and the obtained extinguishing efficiency [1, 3–5, 7]. Therefore, the research on construction of the Turbo type fire-hose nozzles and parameters of streams produced by them are constantly carried out. In Poland the leading research centre is The Main School of Fire Service. Another research and development centre in Poland is The Scientific and Research Centre for Fire Protection – National Research Institute (CNBOP-PIB) in Józefów. Researchers are still looking for technical solutions, which will be able to provide water streams application with as good as possible extinguishing efficiency in various conditions. Unfortunately, the majority of articles and other references present the results of experiments conducted in closed space with the usage of such extinguishing devices as sprinklers, fog heads, etc., which are used mainly in the technical building protection systems [3, 7, 9–12]. It is clear that there is a lack of literature about the research carried out in the open air in real weather conditions with the usage of the Turbo type fire-hose nozzles [13, 15].

The aim of the following article is to evaluate the influence of the spray angle on sprinkling intensity distribution in the spray water stream generated by the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at two flow rates: 200 dm^3/min and 400 dm^3/min and three spray angles: 30°, 60° and 90°. There has been also made an attempt to compare the properties of obtained streams at two different flow rates.

1. Methodology and research procedure

1.1. The aim of the research and its subject

The main aim of the research was to analyse the influence of the spray angle on the sprinkling intensity distribution in the spray stream atomized in the open air by the selected Turbo type fire-hose nozzle.

The subject of research was the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER produced by AWG company. The view of it is shown in Fig. 1.

Fig. 1. The view of the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER
Source: [16]

The selected fire-hose nozzle is widely used in firefighting and rescue units in Poland. Thanks to the flow rate swivel ring it is possible to select the water flow rate in the range of 100/200/300/400 dm^3/min (these values are obtained during the work under operating pressure 6 bar). The spray form (pattern) can be adjusted by rotating the fire-hose nozzle head. It is possible to produce streams from straight jets to spray streams with a spray angle up to 160°, which are often used for personnel protection [17]. The finest atomization is provided by the rotating plastic toothed ring. The selected fire-hose nozzle has an actual certificate of admittance No. 2403/2015 issued by CNBOP-PIB [18].

1.2. Test stand

The measurements were performed on the site located in front of the gate of The Firefighting and Rescue equipment laboratory of The Main School of Fire Service. All experiments were carried out in the open air in August and September 2017.

The scheme of the test stand is presented in Fig. 2.

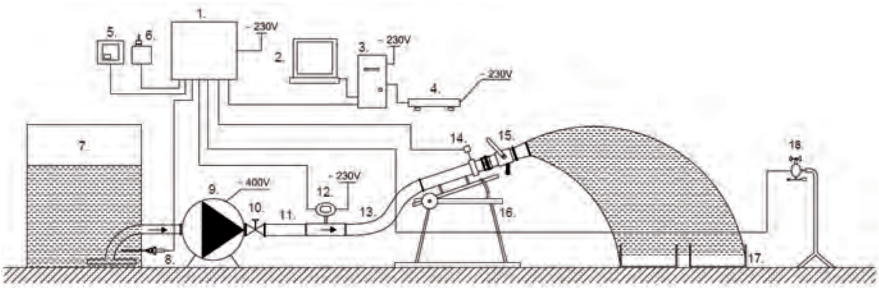

Fig. 2. The scheme of the test stand

1 – electronic control cubicle; 2 – monitor, 3 – PC; 4 – precision laboratory scale; 5 – temperature converter; 6 – atmospheric pressure transmitter; 7 – two water tanks with total net capacity > 1,5 m^3; 8 – Pt 100Ω/0°C temperature sensor; 9 – three vertical, non-self-priming, multistage, in-line, centrifugal pump connected in series; 10 – shut-off valve; 11 – short length fire hose type W-52; 12 – electromagnetic flowmeter; 13 – short length fire hose type W-52; 14 – pressure transmitter; 15 – tested fire-hose nozzle; 16 – metal stand with function of adjustment of inclination angle, 17 – measuring containers with cross-section of inlet surface of 325 mm × 225 mm; 18 – electronic anemometer and wind direction meter

Source: own analysis

1.3. Course of research

The measurements of the sprinkling intensity were performed on the basis of authorial improved test methodology patterned upon the guidelines for control research of average and maximum throw and width of the generated spray stream included in the old Polish PN-89/M-51028 standard [19]. According to the requirements of [19], it was possible to carry out the experiments in the open air in the appropriate weather conditions – the days without rainfall and with the maximum wind speed < 1 m/s.

During each single research the following parameters were measured:

1. t_p – duration of each single measurement, min;
2. t_o – ambient temperature (mean value), °C;
3. p_{atm} – atmospheric (ambient) pressure (mean value), hPa;
4. p_{pr} – pressure at the intake of tested fire-hose nozzle (mean value), bar;
5. Q – water flow rate (mean value), dm^3/min;
6. t_w – water temperature during each single measurement (mean value), °C;
7. v_w – wind speed (mean value), m/s.

The measurement parameters, which are listed above, were continuously monitored and recorded during each single research using devices and check meters. All devices and check meters were connected to the electronic control cubicle. Digital signals from the electronic control cubicle were sent to the PC. Thanks to specially designed the InTouch WindowViewer 2014 R2 SP1 computer software, it was possible to monitor the measurement parameters on the monitor screen continuously (Fig. 3). Special computer application allows also to save data and send them to the file of MS Excel format. During each single experiment the wind direction was also measured. The value of this parameter was assessed in the numeric format. According to the knowledge of the authors, the numeric value of wind direction would not reflect the real impact of this factor on the obtained results. Therefore, the influence of air movement on the results was characterized in a descriptive manner.

The tested fire-hose nozzle was firmly fixed in a metal stand at 15° angle to the ground. The distance between the fire-hose nozzle head and the level of the ground was 1,4 m. The tested fire-hose nozzle was supplied by three vertical, non-self-priming, multistage, in-line, centrifugal pump connected in series. The droplets from the produced spray stream were falling down into the measuring containers, which were arranged in a special order creating a regular grid. The scheme of the special regular grid is shown in Fig. 4. All 210 used measuring containers had the same dimensions (cross-section of inlet surface of 325 mm × 225 mm) and approximately the same weight (~0.571 kg). The spray angle was measured in each single experiment using the digital angle measuring device the GAM 270 MFL Professional produced by Bosch, which is shown in Fig. 5.

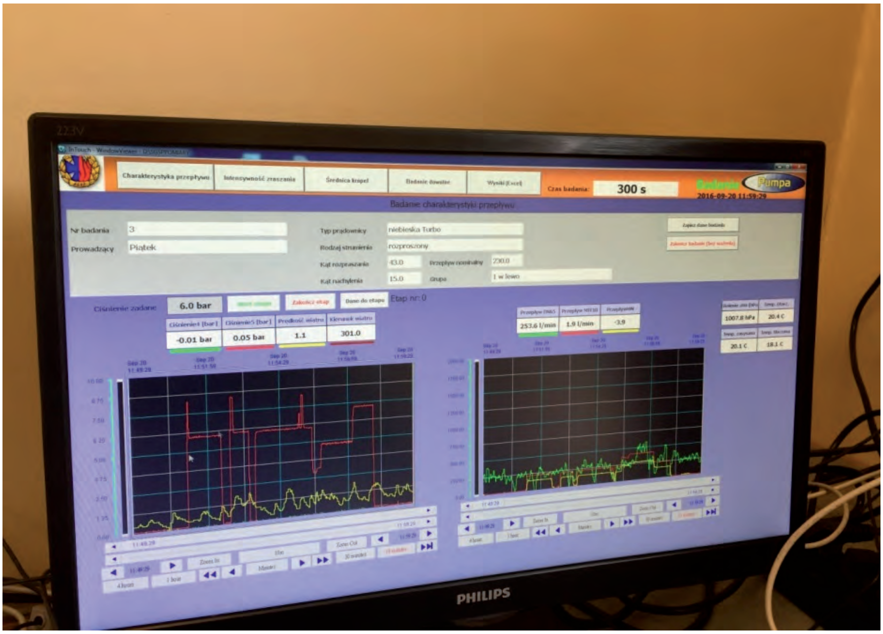

Fig. 3. The view of the window with the InTouch WindowViewer 2014 R2 SP1 computer software during the test

Source: [20]

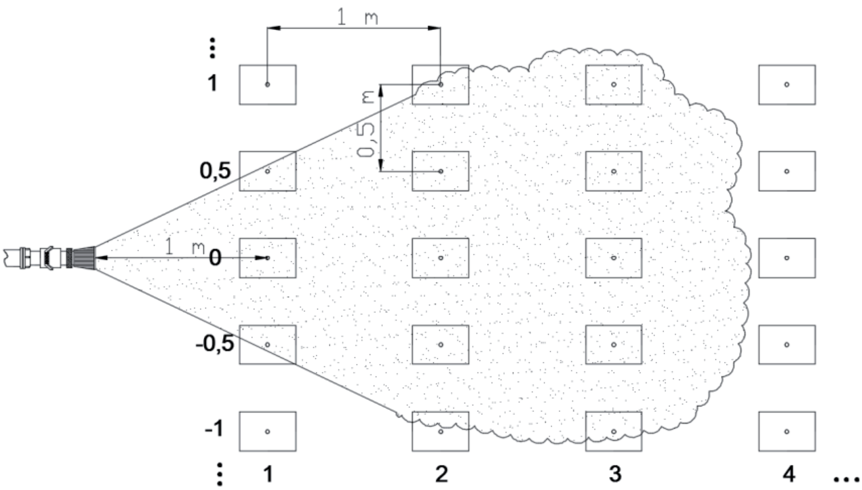

Fig. 4. Schematic diagram of special regular grid of measuring containers

Source: [20]

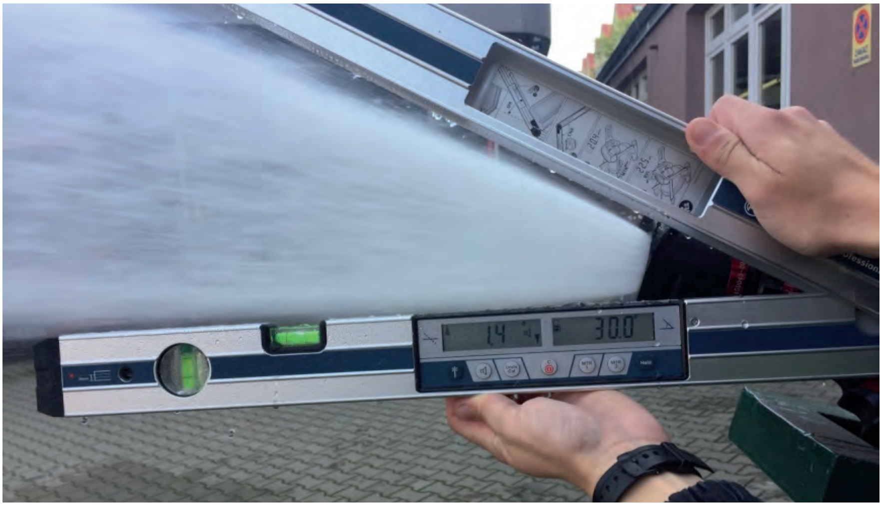

Fig. 5. The measurement of the spray angle during one of the research
Source: [20]

Minimal duration of each single measurement was 2 minutes, but in fact, all experiments were carried out as long as it was possible (paying attention to avoiding spilling of the water from the measuring containers). The amount of water was assessed in a weight and volumetric way. The mass of water which fell down in each single measuring container was weighed by a precision scale WLC 60/C2/K produced by RADWAG after each single test. The temperature of water measured in each single experiment allowed to assess the density of water using the physical and chemical tables. With that, the mass of water was converted into the volume of water. With all the necessary values of variables it was possible to assess the sprinkling intensity I_z. It was calculated by using the formula (1) below:

$$I_z = \frac{V_w}{A_p \cdot t_p} = \frac{m_w}{\rho_w \cdot A_p \cdot t_p} \left[\frac{mm}{min}\right] \tag{1}$$

where:
V_w – volume of water in each single measurement container, mm^3;
A_p – cross-sectional area of inlet surface of measuring container ($A_p = 73125$ mm^2);
t_p – duration of each single measurement, min;
m_w – mass of water in each single measurement container, g;
ρ_w – density of water in each single measurement container, g/mm^3.

The view of the test stand and the real special regular grid of measuring containers before one of the experiments is shown in Fig. 6.

Fig. 6. The view of the test stand and the real special regular grid of measuring containers before one of the experiments

Source: [20]

2. Results of the research

Values of parameters, which were monitored during each single test of the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER, are shown in Tab. 1–6. For mean values the values $\bar{x}$ of its standard deviations σ were calculated and included in the same tables.

Tab. 1. The values of parameters and their standard deviations obtained for the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at the water flow rate of 200 dm³/min and the spray angle of 30°

Parameters	t_p [min]	t_o [°C]	p_{atm} [hPa]	p_{pr} [bar]	Q [dm³/min]	t_w [°C]	v_w [m/s]
$\bar{x}$	8.50	21.7	993	6.42	200.5	19.0	1.31
σ	–	0.0	0	0.04	0.6	0.0	0.78

Source: [20]

Tab. 2. The values of parameters and their standard deviations obtained for the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at the water flow rate of 200 dm³/min and the spray angle of 60°

Parameters	t_p [min]	t_o [°C]	p_{atm} [hPa]	p_{pr} [bar]	Q [dm³/min]	t_w [°C]	v_w [m/s]
$\bar{x}$	7.00	21.7	993	6.77	200.6	18.6	0.92
σ	–	0.0	0	0.04	0.7	0.0	0.48

Source: [20]

Tab. 3. The values of parameters and their standard deviations obtained for the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at the water flow rate of 200 dm³/min and the spray angle of 90°

Parameters	t_p [min]	t_o [°C]	p_{atm} [hPa]	p_{pr} [bar]	Q [dm³/min]	t_w [°C]	v_w [m/s]
$\bar{x}$	7.00	20.5	1008	6.60	200.0	19.3	1.03
σ	–	0.1	0	0.06	1.1	0.1	0.33

Source: [20]

Tab. 4. The values of parameters and their standard deviations obtained for the nozzle fire-hose PWT 52/1-2-3-4 type TURBOMASTER at the water flow rate of 400 dm³/min and the spray angle of 30°

Parameters	t_p [min]	t_o [°C]	p_{atm} [hPa]	p_{pr} [bar]	Q [dm³/min]	t_w [°C]	v_w [m/s]
$\bar{x}$	5.67	20.8	1008	5.55	398.7	17.8	0.44
σ	–	0.0	0	0.04	1.4	0.0	0.25

Source: [20]

Tab. 5. The values of parameters and their standard deviations obtained for the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at the water flow rate of 400 dm³/min and the spray angle of 60°

Parameters	t_p [min]	t_o [°C]	p_{atm} [hPa]	p_{pr} [bar]	Q [dm³/min]	t_w [°C]	v_w [m/s]
$\bar{x}$	4.00	20.8	1008	5.23	398.5	17.9	0.66
σ	–	0.1	0	0.05	1.6	0.1	0.28

Source: [20]

Tab. 6. The values of parameters and their standard deviations obtained for the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at the water flow rate of 400 dm³/min and the spray angle of 90°

Parameters	t_p [min]	t_o [°C]	p_{atm} [hPa]	p_{pr} [bar]	Q [dm³/min]	t_w [°C]	v_w [m/s]
$\bar{x}$	3.75	20.2	1008	4.22	398,4	18,2	0,63
σ	–	0.0	0	0.13	5.7	0.0	0.47

Source: [20]

Graphic visualisation of the basic measured parameter – the sprinkling intensity I_z was done using the computer program SURFER 15 produced by Golden Software Inc. The charts in Fig. 7–8 depict the sprinkling intensity distribution in three-dimensional arrangement. Classic coordinate system X, Y, Z in the charts was replaced by the S, L, I_z coordinate system, where:
S – distances between measuring containers in direction perpendicular to axis of the nozzle, m;
L – distances between measuring containers in direction parallel to axis of the nozzle, m;
I_z – sprinkling intensity in each single measuring container, mm/min.

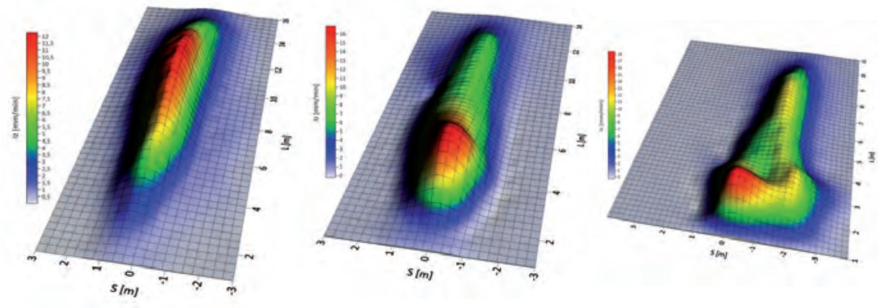

Fig. 7. The sprinkling intensity distribution in three-dimensional arrangement obtained for the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at the water flow rate of 200 dm³/min and the spray angle of 30° (on the left side) and 60° (in the middle) and 90° (on the right side)
Source: own analysis based on [20]

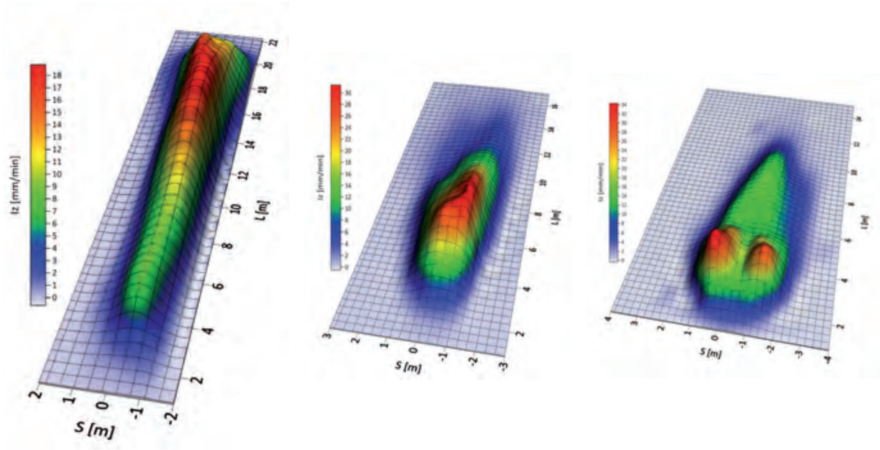

Fig. 8. The sprinkling intensity distribution in three-dimensional arrangement obtained for the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at the water flow rate of 400 dm³/min and the spray angle of 30° (on the left side) and 60° (in the middle) and 90° (on the right side)

Source: own analysis based on [20]

Thanks to the program SURFER 15 it was possible to create two other types of charts based on the obtained results. The charts illustrate sprinkling intensity distribution in two-dimensional arrangement and show its distribution along the central (longitudinal) axis. Some examples of these types of charts are shown in Fig. 9–10.

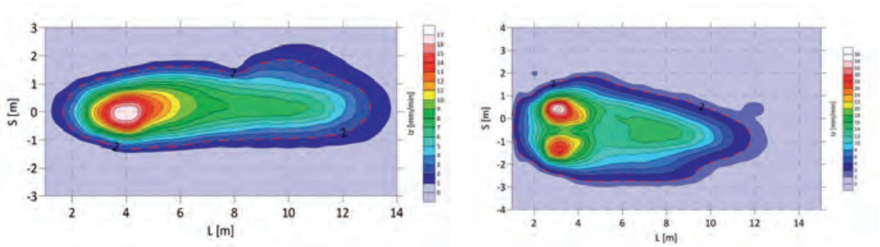

Fig. 9. The sprinkling intensity distribution in two-dimensional arrangement obtained for the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at the water flow rate of 200 dm³/min and the spray angle of 60° (on the left side) and at the water flow rate of 400 dm³/min and the spray angle of 90° (on the right side)

Source: own analysis based on [20]

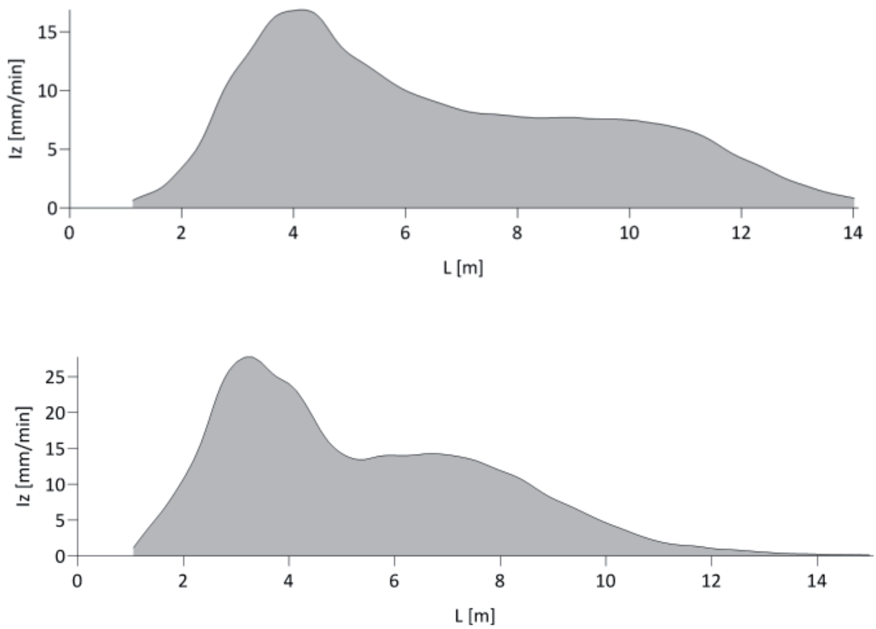

Fig. 10. The sprinkling intensity distribution along the central (longitudinal) axis obtained for the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at the water flow rate of 200 dm^3/min and the spray angle of 60° (on the left side) and at the water flow rate of 400 dm^3/min and the spray angle of 90° (on the right side)

Source: own analysis based on [20]

3. Analysis of the obtained results

The analysis of the obtained results of the research can be conducted in many various ways. In this article the authors have limited the analysis to a few important parameters. The following key factors were taken into consideration in the presentation of the obtained results:

1. the sprinkling area A_z defined as the area in which value of $I_z \geq 2$ mm/min,
2. the maximum value of the sprinkling intensity $I_{z\,max}$ defined as the maximum value (global extremum) of sprinkling intensity I_z inside the borders of the sprinkling area A_z,

3. the maximum throw (range) of the generated spray stream L_{max} defined as the distance measured lengthwise from the fire-hose nozzle head to the furthest point in which value of $I_z \geq 2$ mm/min,
4. the number of local extrema L_{el} defined as the number of points in which the sprinkling intensity I_z gets the highest value locally.

The values of all above listed parameters obtained for the spray streams produced by the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER for two different water flow rates 200 dm^3/min and 400 dm^3/min and three spray angles: 30°, 60° and 90°, were presented in Tab. 7.

Tab. 7. The values of the parameters adopted for the analysis obtained for the spray streams produced by the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at two different water flow rates 200 dm^3/min and 400 dm^3/min and three spray angles: 30°, 60° and 90°

Q [dm^3/min]	φ [°]	p_{pr} [bar]	A_z [m^2]	$I_{z\,max}$ [mm/min]	L_{max} [m]	L_{el} [–]
200	30	6.42	28.06	12.24	15.14	1
	60	6.77	27.05	16.90	13.02	1
	90	6.60	25.01	18.42	10.20	2
400	30	5.55	44.65	18.85	20.56	2
	60	5.23	38.45	31.36	15.15	1
	90	4.22	36.10	34.29	11.80	2

Source: own analysis based on [20]

Apart from the tabulated form the values of the parameters adopted for the analysis are also presented in a graphic form. The charts in Fig. 11–13 depict the values of three selected parameters A_z, $I_{z\,max}$ and L_{max} as a function of the spray angle φ. The characteristic dependences observed in the charts were approximated linearly (by straight-line function) and by polynomial functions. They were marked in the charts with the trend lines.

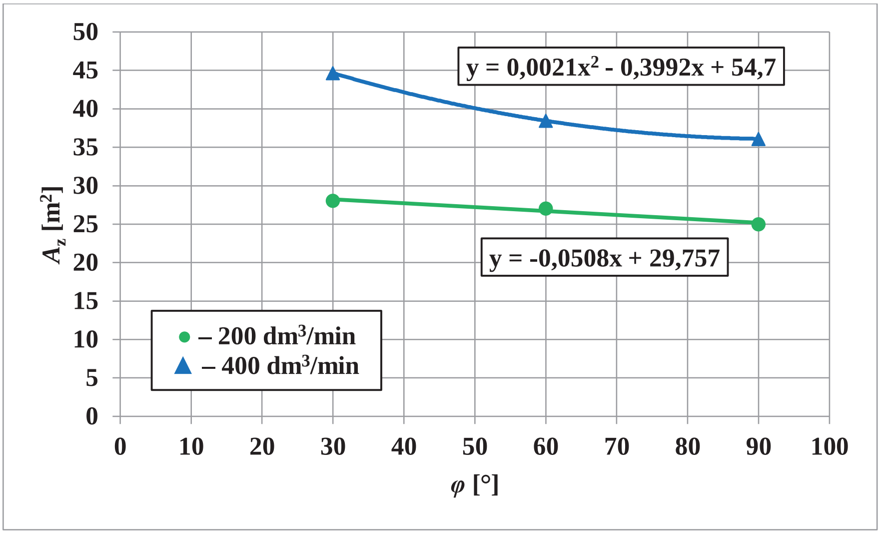

Fig. 11. The values of the sprinkling area A_z obtained for the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at three spray angles (30°, 60° and 90°) and two water flow rates (200 dm³/min and 400 dm³/min)

Source: own analysis

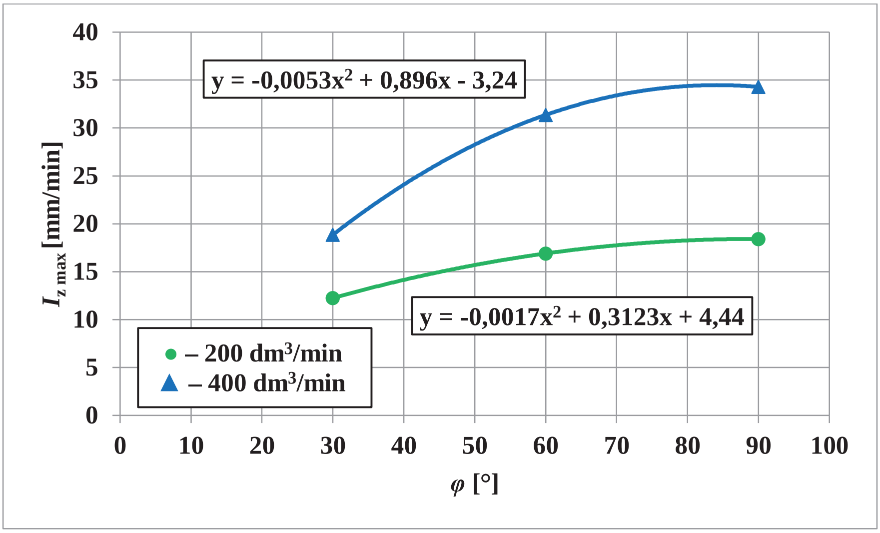

Fig. 12. The values of the maximum value of the sprinkling intensity $I_{z\,max}$ obtained for the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at three spray angles (30°, 60° and 90°) and two water flow rates (200 dm³/min and 400 dm³/min)

Source: own analysis

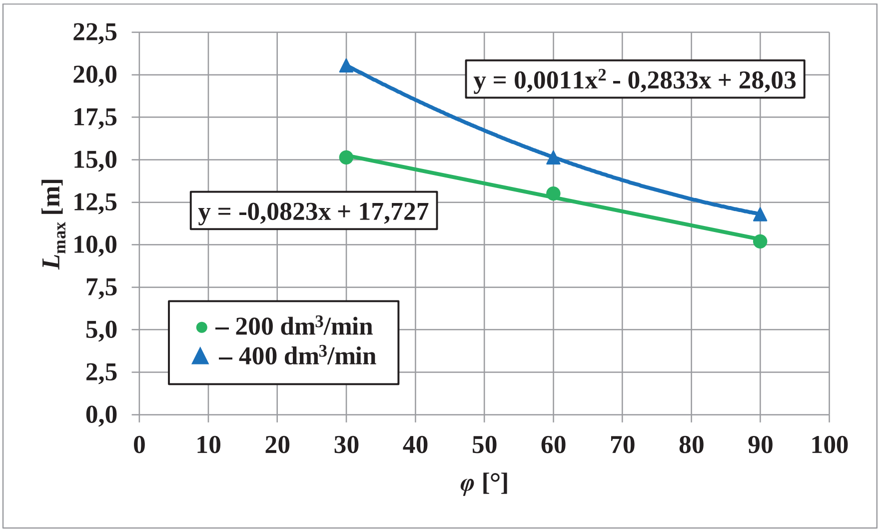

Fig. 13. The values of the maximum throw (range) of the generated spray stream L_{max} obtained for the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER at three spray angles (30°, 60° and 90°) and two water flow rates (200 dm³/min and 400 dm³/min)

Source: own analysis

Summary and conclusions

The results of the experiments enabling to analyse the impact of the spray angle on sprinkling intensity distribution in the spray water stream generated by the fire-hose nozzle PWT 52/1-2-3-4 type TURBOMASTER for following two different flow rates 200 dm³/min and 400 dm³/min and three different spray angles 30°, 60° and 90°, have been presented and discussed in details. Basing on the results obtained during the tests, the following general and specific conclusions can be formulated:

1. The highest values of the sprinkling area A_z (for both flow rates) are obtained for the minimum values of the spray angles φ. The main reason of this, is the fact, that these surfaces have significantly longer central (longitudinal) axis than other sprinkling areas obtained during the research. With the increase of the spray angle φ the sprinkling area A_z decreases – for the water flow rate of 200 dm³/min linearly according to the following equation $A_z(\varphi) = -0{,}0508\varphi + 29{,}757$ and for the water flow rate of 400 dm³/min in

exponential function. The greatest change of the sprinkling area A_z was obtained for the water flow rate of 400 dm^3/min at the change of the spray angle from 30° to 60° (decrease of 6.20 m). The decrease of the values of the sprinkling area A_z at the change of the spray angle from 60° to 90° was over 2.6 times lower. Interestingly, for the water flow rate of 200 dm^3/min a greater decrease of the sprinkling area A_z was caused by the change of the spray angle from 60° to 90° than by the change from 30° to 60°.

2. With the increase of the spray angle φ (for both flow rates) the values of the maximum value of the sprinkling intensity $I_{z\,max}$ increases in exponential function. For both flow rates, it was also observed, that the changes are bigger for the change of spray angle from 30° to 60° than by the change from 60° to 90°. Similarly to the case of the parameter of A_z, the most significant change of the parameter $I_{z\,max}$ was observed for the water flow rate of 400 dm^3/min at the change of the spray angle from 30° to 60° (in this case it was the increase of 12.51 m^2). The highest values of the maximum value of the sprinkling intensity $I_{z\,max}$ were obtained for both flow rates at the spray angle of 90°. However, for the water flow rate of 200 dm^3/min the obtained value is significantly lower than the value obtained for the water flow rate of 400 dm^3/min (accurately over 1.8-fold lower).
3. Similarly to the parameter A_z, the highest values of the maximum throw (range) of the generated spray stream L_{max} are obtained at the lowest spray angles φ. The main reason of this, is the greatest kinetic energy of these water streams. The differences between the values of parameter of L_{max} obtained for both flow rates at the spray angles of 60° and 90° are minor (they do not exceed 2.2 m). The greater differences were only observed for the spray angle of 30° – the obtained value of the parameter of L_{max} for the water flow rate of 400 dm^3/min is almost of 5.5 m greater than the same value obtained for the water flow rate of 200 dm^3/min. For the water flow rate of 200 dm^3/min the values of the maximum throw (range) of the generated spray stream L_{max} decrease linearly according to the following function $L_{max}(\varphi) = -0{,}0823\varphi + 17{,}727$.
4. The change of the spray angle φ causes the change of the shape of the sprinkling area A_z from the elliptical with significantly longer central (longitudinal) axis for the spray angle of 30°, through elliptical with slightly less lengthened central (longitudinal) axis (similar to oval) for spray angle of 60°, up to similar to isosceles triangle for the spray angle of 90°.

5. Generally, it can be assumed that for the spray angles of 30° and 60° in the sprinkling area there is one local extremum, which is also the global extremum. For the spray angle of 90° two local extrema were noticed. These extrema are equidistant from the real central (longitudinal) axis of the sprinkling area nearby the head of the tested fire-hose nozzle. After careful analysis, it was found that the occurrence of two extrema for the research, which was carried out for the water flow rate of 400 dm^3/min at the spray angle of 30°, was the result of the disturbances caused by the wind. With great simplicity, it can be assumed that at the spray angle of 30° the local extremum (at the same time the global one) is located on the real central (longitudinal) axis of the sprinkling area near the farthest end of this area. For the spray angle of 60° the situation looks similar, however, the local extremum (at the same time the global one) is located closer to the head of the tested fire-hose nozzle, thus closer to the beginning of the sprinkling area. For the spray angle of 90°, the local extrema are located near two tops (located closer to the head of the tested fire-hose nozzle) of isosceles triangle formed by the sprinkling area.
6. The influence of the air movement on the obtained results of the research can be mainly seen thanks to the analysis of the charts in a three-dimensional arrangement. In the charts, all deformations of the sprinkling area e.g. displacement of the central (longitudinal) axis of the obtained sprinkling area in relation to the longitudinal axis of the tested fire-hose nozzle (the point 0 on the S axis), were clearly visible.

Taking into consideration the fact that there is an obvious lack of these types of publications in scientific and professional literature (especially connected with the measurements performed in the open air) the authors recognise the necessity and validity of further research and experiments in this field of firefighting. Research studies should depict an atomization of spray streams generated by the fire-hose nozzles of various constructions for different spray angles and water flow rates. The researchers all over the world should pay attention especially to modern fire-hose nozzles and specialized fire-hose nozzles, such as fog nozzles or combined nozzles [21, 22]. An assessment of influence of the mentioned factors on sprinkling area and thus extinguishing efficiency should be made in further studies.

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